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G01V 3/28

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(56) Documents Cited
EP 0475715 A2 US 5095272 A US 4302723 A

(58) Field of Search
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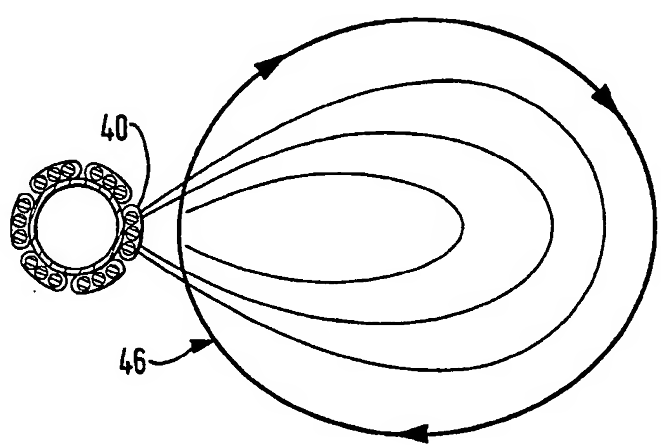
Online : wpi

(54) Directional induction logging instrument

(57) An induction logging instrument for making directional conductivity/resistivity measurements comprises at least one transmitter coil 40 wound on a magnetic core and supported on an elongate former. A plurality of receiver coils 50 are longitudinally spaced from the transmitter coil and are responsive to ground currents 46 generated by the transmitter coil. The receiver coils are arranged at angularly spaced positions around the circumference of the instrument.

FIG.7b



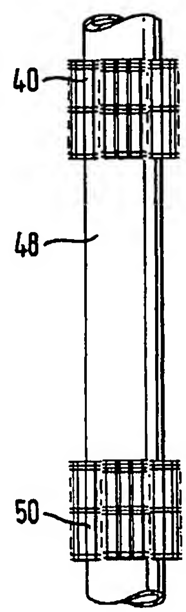


FIG.8

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

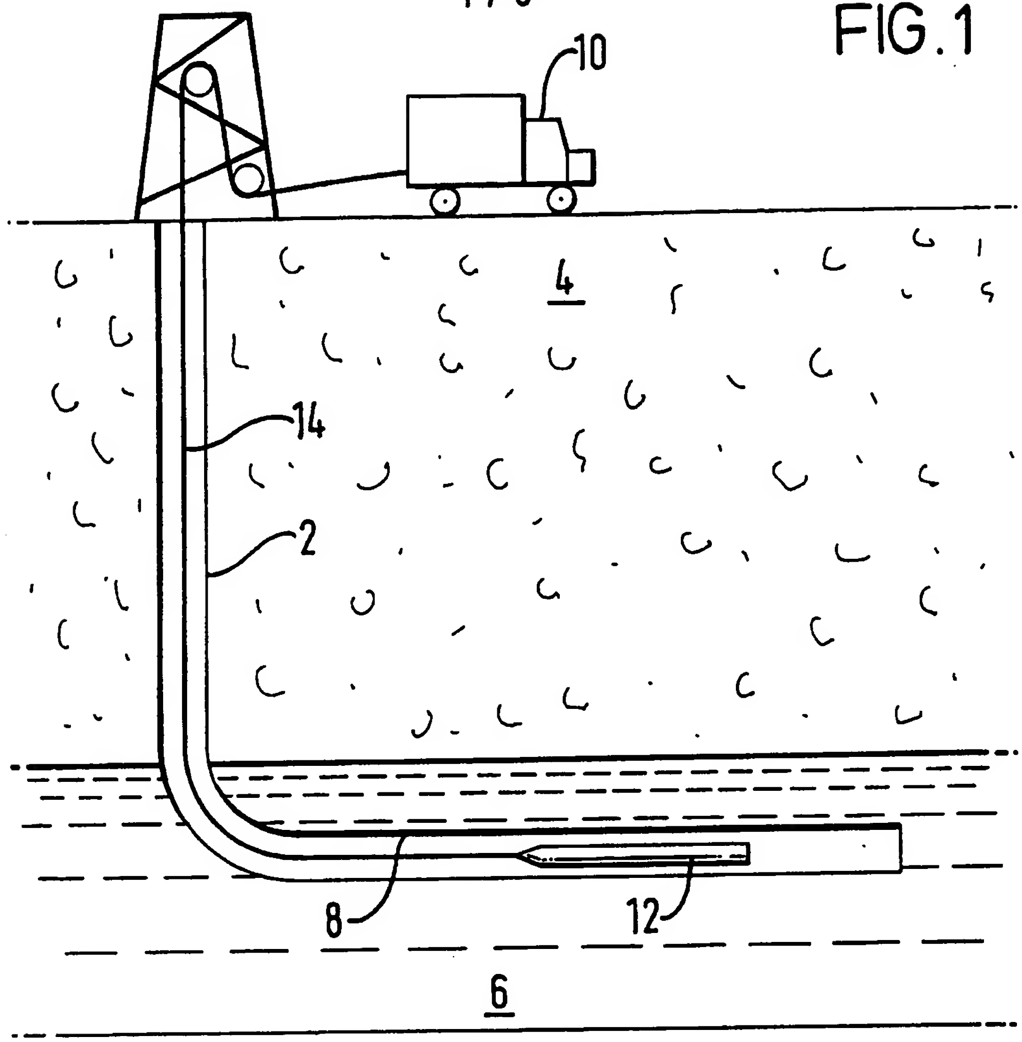


FIG.1

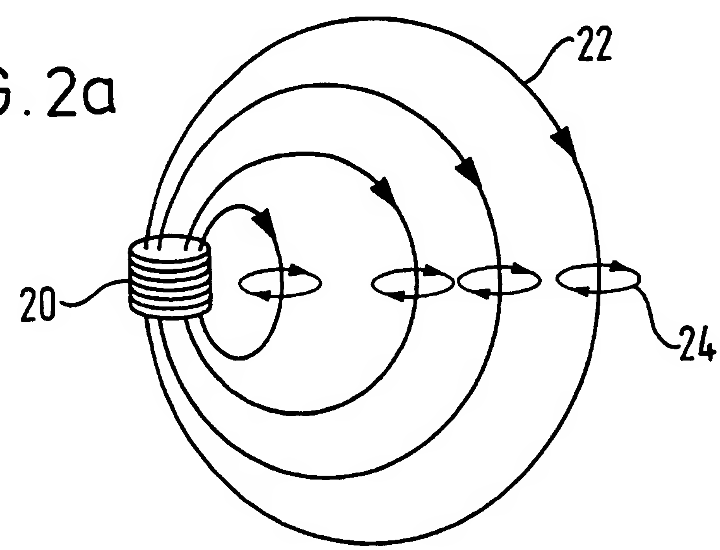


FIG. 2a

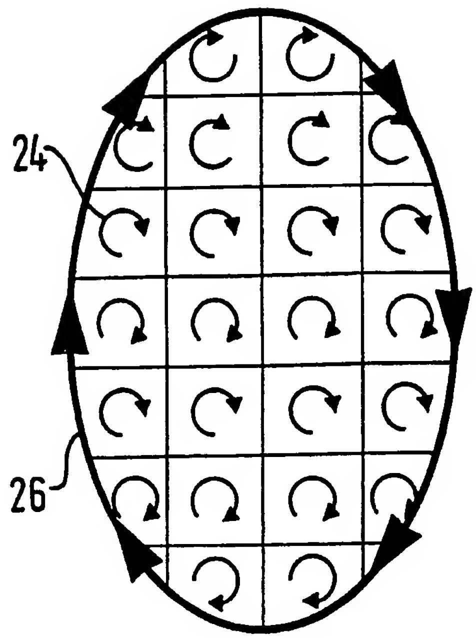


FIG. 2b

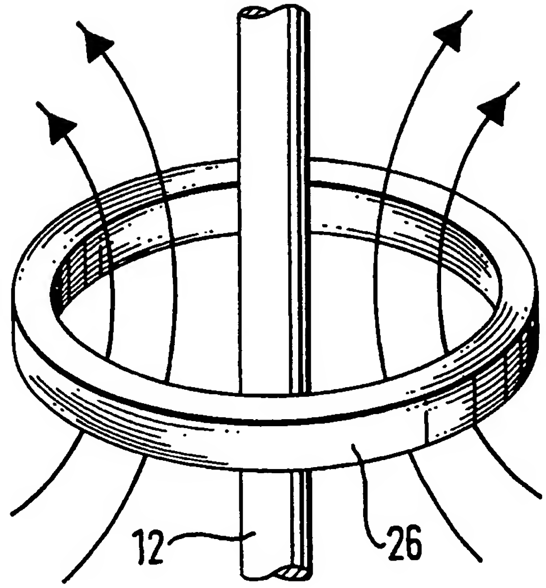


FIG. 3

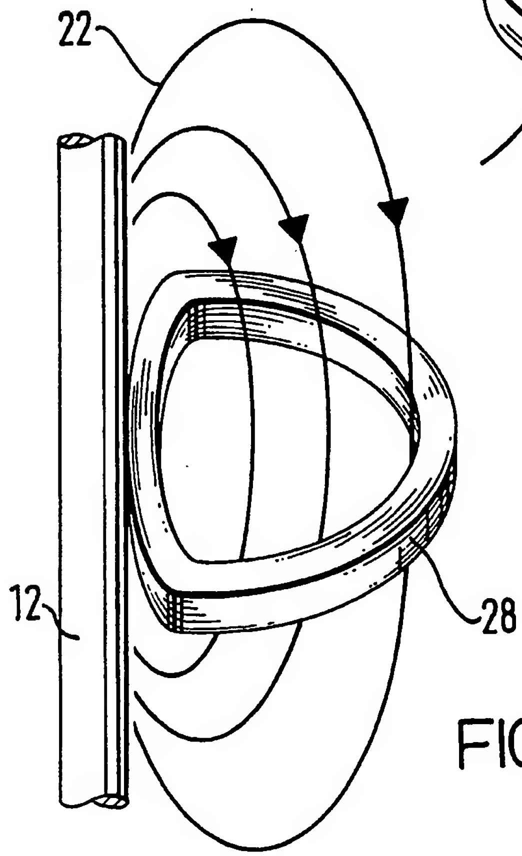


FIG. 4

FIG. 5

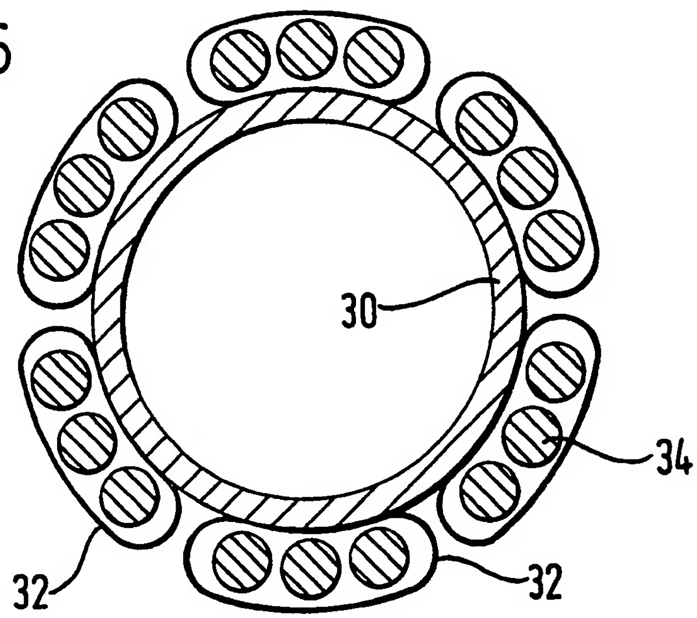
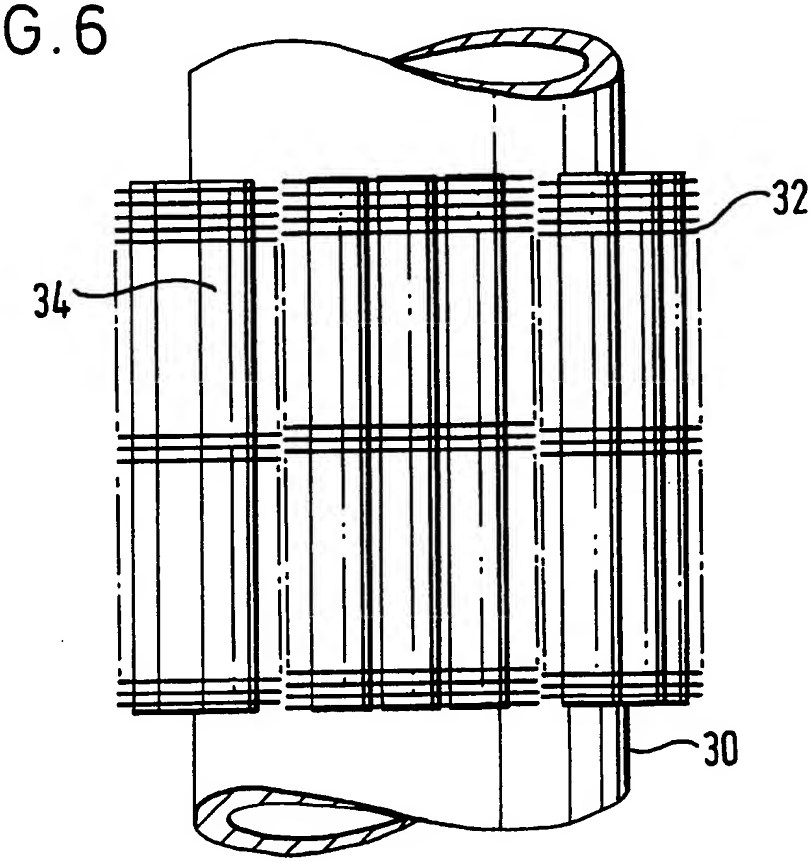


FIG. 6



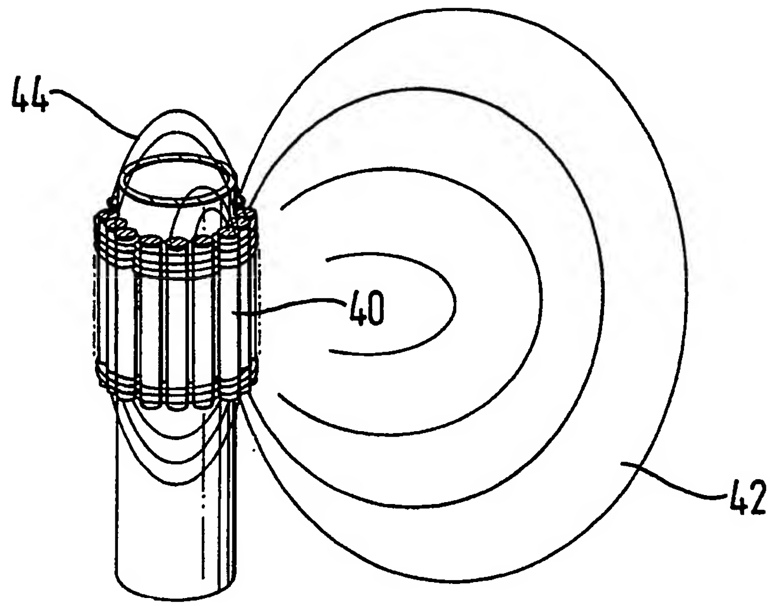
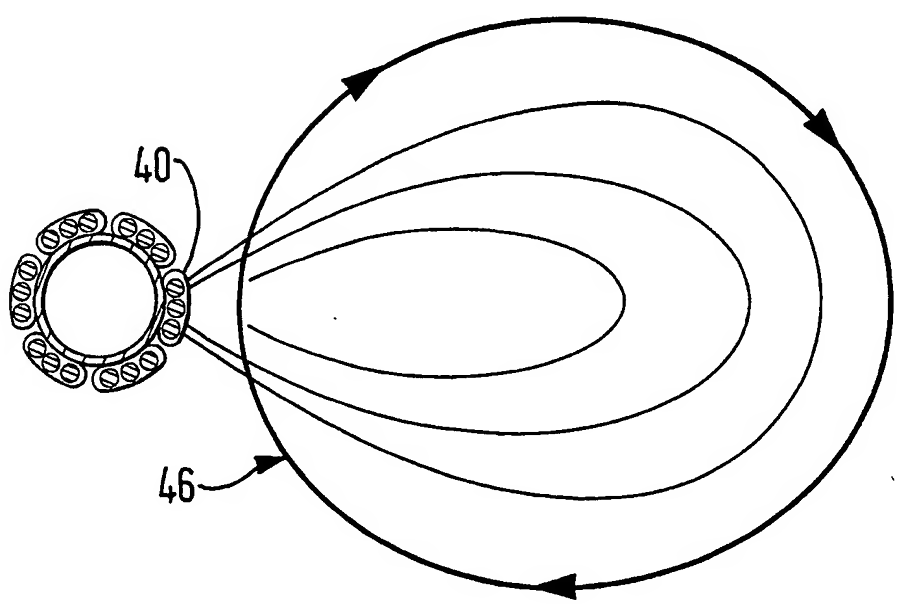


FIG. 7a

FIG. 7b



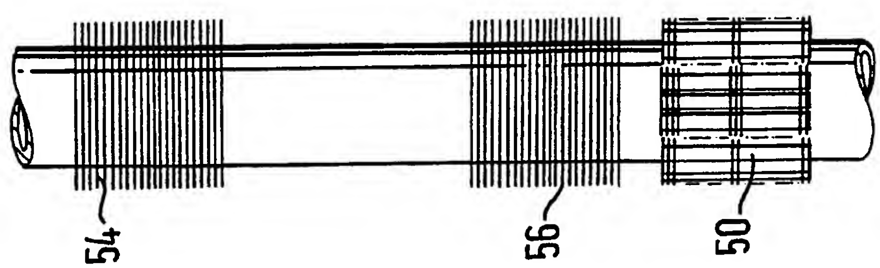


FIG.11

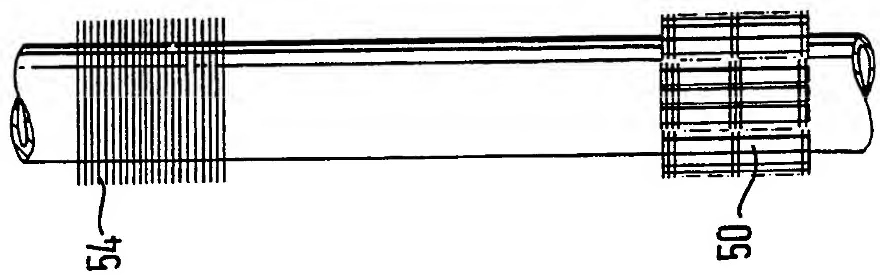


FIG.10

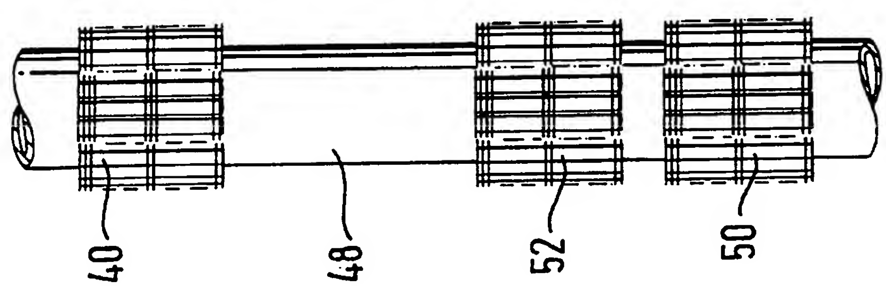


FIG.9

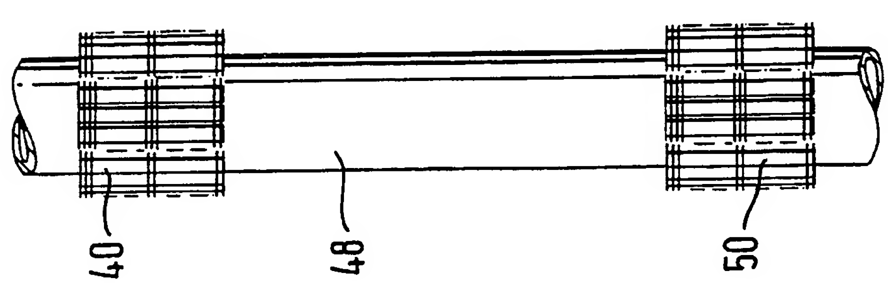


FIG.8

FIG.12a

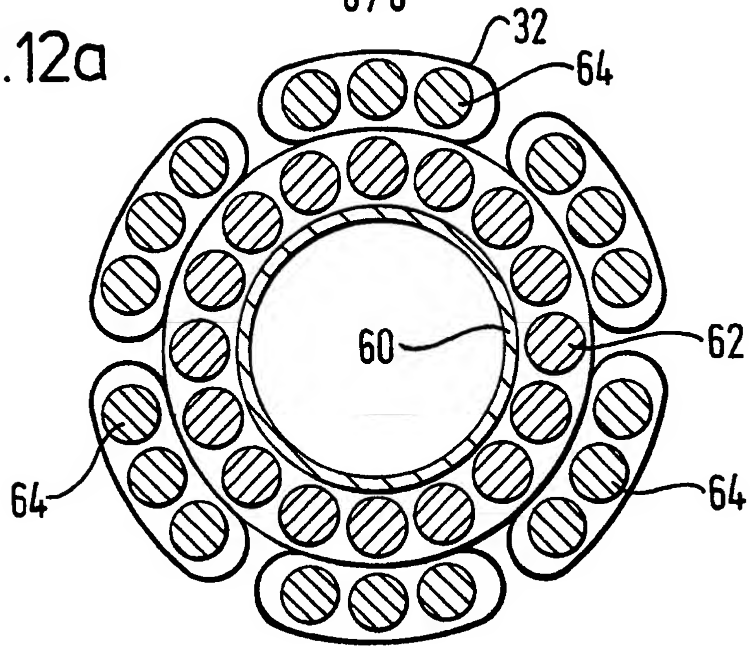
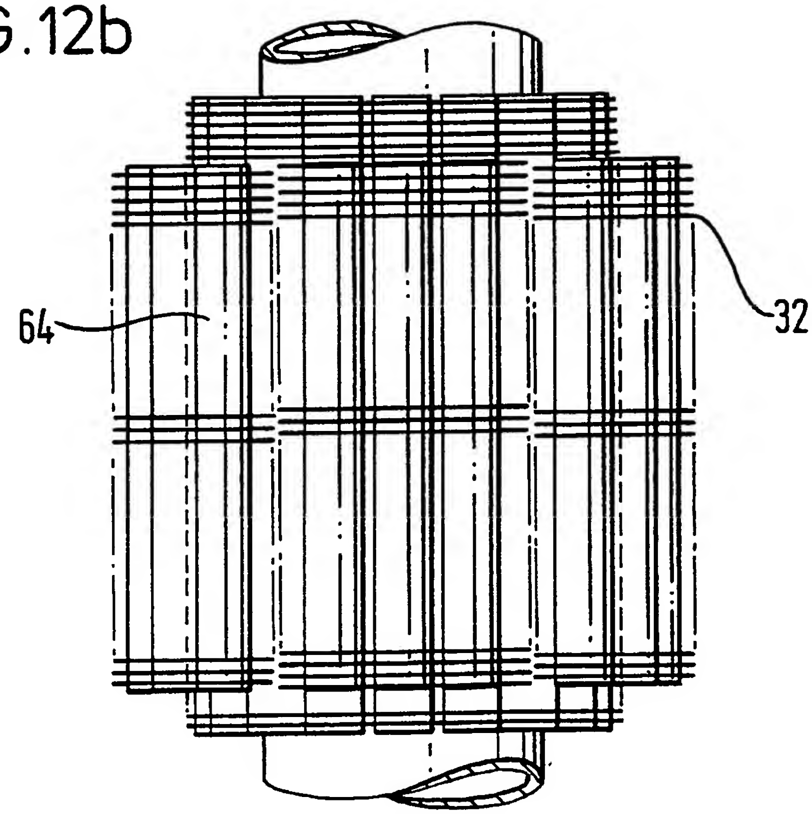


FIG.12b



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INDUCTION LOGGING INSTRUMENT

This invention relates to induction logging instruments of the type which may be used to measure the resistivity/conductivity of a formation down a borehole either as part of an instrument string or in a measurement while drilling application, and in particular to an induction logging instrument which may make directional resistivity/conductivity measurements circumferentially around a borehole.

When drilling for oil, it has become accepted practice to commence by drilling a borehole vertically down to the reservoir and then to deviate the drill bit such that the borehole becomes horizontal in the reservoir itself. The purpose of this deviation is to increase the drainage efficiency for removing the oil from the reservoir and, because of this, the horizontal section of the borehole is usually drilled along the upper side of the oil reservoir, as close to the retaining cap rock as is possible.

Figure 1 illustrates this drilling scheme. It shows a borehole 2 drilled through cap rock 4 which retains oil in an oil reservoir 6. When the borehole reaches the oil reservoir it deviates by 90° and forms a horizontal portion 8. As illustrated, a mobile wireline logging station 10 may lower instrumentation such as an induction logging instrument 12 into the borehole via a cable 14.

The induction logging instrument 12 (induction sonde) is used to measure the formation resistivity/conductivity in the oil reservoir. In the situation illustrated in Figure 1 where the borehole is horizontal near the top of the reservoir the formation resistivity is not axially symmetric around the borehole.

A conventional induction logging instrument operates by having at least one transmitter coil wound around a former and one or more receiver coils longitudinally spaced from the transmitter coil along the former. Energisation of the transmitter coil causes ground currents to flow in a loop around the instrument.

The magnetic field associated with these ground currents induces current in the receiver coils, the magnitude of which is dependent on the formation resistivity/conductivity.

As the conventional induction logging instrument relies on axial symmetry to achieve accurate measurements it will not produce a useful result in the position shown in Figure 1. The instrument in Figure 1 is in a formation in which the resistivity changes around its circumference and thus it will not produce any meaningful result concerning resistivity of the oil bearing formation.

In EP-A-0475715 there is proposed an instrument for making directional measurements around a borehole. In this transmitter coils are placed asymmetrically around a conductive former in slots formed in the former. The positioning of the transmitter coils results in nulls being formed in the primary magnetic field formed by the transmitter coil. Receiver coils are placed at these nulls thereby eliminating the need for any cancellation coil to eliminate the primary field effects in receiver coils. A fundamental problem associated with an instrument of this type is that the electrical properties of the conductive former change with temperature in a borehole. This results in changes in the primary field and changes in the positions of directional nulls. Thus spurious signals are generated at receiver coils and compensation for these is difficult.

In our European patent application number 943027268 there is proposed an induction logging instrument for use in measurement while drilling applications. In this the former on which the coils are wound may be conductive or non-conductive. The former is screened from the field generated by the transmitter coil by a layer of magnetic core material on which the coil is wound. When a non-conductive former is used a directional instrument of the type described in EP-A-0475715 cannot be used because no nulls will be formed for receiver coil placement.

Preferred embodiments of the present invention provide an induction logging instrument which can

selectively measure resistivity/conductivity, in particular radial directions. The instrument is preferably constructed so that it can measure the resistivity of the surrounding formation in a plurality of segments around the circumference of the logging instrument with either a conductive or a non-conductive former.

The invention is defined with more precision in the appended claims to which reference should now be made.

Preferred embodiments of the instrument will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows the borehole discussed above;

Figures 2a and 2b schematically show the generation of ground currents by a current flowing in a coil;

Figure 3 schematically shows a ground current generated by a conventional induction logging instrument;

Figure 4 schematically shows a ground current generated by a logging instrument embodying the present invention;

Figure 5 shows a schematic cross-section through a logging instrument embodying the present invention;

Figure 6 shows a side view of one of the coil systems of the instrument of Figure 5;

Figures 7a and 7b schematically show in side and plan cross-sections the field patterns generated by an embodiment of the invention;

Figure 8 shows an instrument embodying the invention with multiple receiver and transmitter coils;

Figure 9 shows the instrument of figure 8 with the addition of a cancellation coil system;

Figure 10 shows an instrument embodying the invention with a single transmitter coil and multiple receiver coils;

Figure 11 shows the instrument of Figure 10 with the addition of a cancellation coil; and

Figure 12 shows a further embodiment of the invention.

The mechanism by which ground currents are induced by an induction logging instrument is illustrated with reference to Figures 2a and 2b. Figure 2a shows a transmitter coil 20 through which an AC current is passed. This generates a varying magnetic field which penetrates into any surrounding conductive medium. The portion of the magnetic field is illustrated in cross-section in Figure 2a as lines of magnetic flux 22.

It can be considered that each line of magnetic flux has a current element 24 circulating round it. Thus a network of circulating current cells is formed. The network for the lines of flux in Figure 2a is shown diagrammatically in Figure 2b. It can be seen that at the boundaries of each cell 24 the currents cancel. Thus there is current generated around the outside of the field and this is illustrated by the thick black line 26. This is the current that flows in the medium penetrated by the magnetic field.

We have appreciated that if the field pattern from an induction logging instrument can be produced such that it is non-axially symmetric, a radial directionality can be imparted to measurements made with the logging instruments.

Figure 3 shows the ground current 26 which is generated around the transmitter coil of a conventional induction logging instrument 12. In a preferred embodiment of the invention a field and current pattern as illustrated in Figure 4 is required. In this, the lines of magnetic flux 22 which are produced have been constrained to be present predominantly on one side of the logging instrument 12 thus producing a non-symmetrical ground current loop 28 which also is predominantly on the same side of the induction logging instrument. This ground current will be detected by receiver coils on the instrument.

In order to produce the asymmetrical field of Figure 4, an arrangement of coils of the type shown in Figures 5 and 6 is proposed. In this, the induction logging instrument comprises a non-magnetic, non-conductive core 30. Carried on the outside of this core

30 are six circumferentially-spaced coils 32 each wound on magnetically-permeable cores 34. Thus it can be seen that none of the coils are actually wound around the core 30. Instead, each one is distorted from the generally circular shape to lie against the outer surface of the core 30 over a portion of its circumference with the axis of the coil being substantially parallel to the axis of the core. In this particular example there are six coils circumferentially spaced around the core. Clearly more or fewer coils could be used.

If one of the coils of Figures 5 and 6 is activated, a magnetic field pattern of the type shown in Figures 7a and 7b will be generated. In Figure 7a the lines of magnetic flux 42 generated as a result of activation of coil 40 carried on the logging instrument extend outwardly from the logging instrument and penetrate the surrounding formation. At the same time, the lines of flux 44 are generated on the opposite side of the coil. The high magnetic permeability of the cores in the other coils around the instrument provide a line of weakest resistance through which these lines of flux pass. Thus virtually no magnetic flux is generated on the other sides of the instrument.

As a result of the lines of flux 42, a ground current loop 46 is generated to one side of the logging instrument. Each of the six coils around the instrument can produce a similar ground current rotationally displaced from that shown in Figure 7b by 60°.

If each of the six coils is activated in turn in response to signals from the surface logging station, six different radial regions of the surrounding formation will have ground current induced in them. These induced currents are detected in the usual manner by the logging station by measuring the currents they themselves induce in a corresponding system of receiver coils.

The whole logging instrument is illustrated with reference to Figure 8 in which six transmitter coils 40 are wound on a non-magnetic core 48. Longitudinally spaced on the core from the transmitter is a geometrically-similar arrangement of receiver coils 50.

When one of the transmitter coils is activated, a current will be induced in at least one of the receiver coils. The coil of most interest is that on the same arc of the instrument as the activated transmitter coil. However, the results from the other coils will enable fine tuning of results to be made.

As with all induction systems the current induced in the receiver coil by the ground current flowing in the formation can be masked by the very large current directly induced by the transmitter coil. Various measures may be employed to reduce the effect of the directly induced signal thus making it possible to measure more accurately the ground currents induced in the formation. These measures are:

1. Pulse or transmit a short burst of current from the transmitter coil. The directly coupled signal disappears as soon as the transmitter pulse ceases. However, the ground current flows for a short time after this. Thus, if the current induced in the receiver coil is measured after the transmitted pulse stops, the effect of the directly induced current is removed and all the receiver coil current is induced by current flowing in the formation.

2. Use a phase sensitive detector. The directly induced signal is 90° out of phase with the transmitter current but the voltages induced by the ground current in the receiver coil are 180° out of phase with the transmitter current. Using a phase sensitive detector to isolate the two out of phase signals induced in the receiver coil will allow them to be measured independently.

3. Use a third coil on the logging instrument for direct induction cancellation. This is illustrated in Figure 9 in which a cancellation coil system 52 is added to the instrument in Figure 8. The cancellation coil arrangement is similar to that of the transmitter coils 40 and receiver coils 50. When the cancellation coil is connected in series the correct phase with the receiver coil, it cancels out all of the directly induced signal but leaves a significant signal from the ground currents.

The exact position of the cancellation coil is selected so as to completely cancel direct currents.

An alternative embodiment of the logging instrument is illustrated in Figure 10. In this the transmitter comprises a single coil symmetrically wound around the logging instrument. The whole of the formation around the circumference of the tool is therefore excited by the transmitter coil. However, the receiver comprises a plurality of coils arranged around the circumference of the instrument such as are illustrated in Figures 5 and 6. Thus only a small region of the formation is interrogated by the receiver and this gives the total measurement the directional properties required. A modification to Figure 10 is shown in Figure 11. In this, a cancellation coil 56 is provided on the instrument for connection with the receiver coils to cancel the directly induced currents.

A further embodiment of the invention is illustrated in Figures 12a and 12b which uses a system as described in our European patent application No. 94302726.8 This enables measurements to be made in a measurement whilst drilling application where the logging instrument is provided on a coiled tubing system adjacent to a down hole motor and drilling bit.

In this embodiment, the instrument is formed on a strong core 60 which is non-magnetic and may be of metal. Around this core 60 is a screen made up of a plurality of elongate sections 62 of magnetically-permeable core material. The purpose of these is to shield the coils surrounding the tube from the drilling mud flowing through the instrument to drive the down hole motor and which may be conductive.

Around the shield sections 62 are coils 32 of the type shown in Figure 5, each wound round elongate sections 64 of magnetically-permeable core material.

When a current flows in one of the coils 32 a field generated in the formation is similar to that illustrated in Figure 7a. However, lines of flux within the instrument do not pass through the central core and the drilling mud flowing therethrough because of the presence of the shield 62. Instead the lines of flux pass

through the magnetically-permeable core material 62. Thus the lines 44 as shown in Figure 7a would in fact only be present on the side of the instrument adjacent to the activated coil and no current would be induced in the coil as a result of conductivity in the drilling mud.

This embodiment may be modified to correspond to that of Figure 10 which has only a single transmitter coil. To do this the transmitter coil would be wound directly around the screen of magnetic core material thereby shielding the coils from drilling mud flowing through the tube.

Thus, using a shield of this nature for transmitter and receiver coils the invention may be used in a measurement whilst drilling application.

CLAIMS

1. An induction logging instrument comprising at least one transmitter coil wound on magnetically permeable core material and supported on an elongate former and a plurality of receiver coils each wound on magnetically-permeable core material and supported at angularly spaced positions around the former at a predetermined axial displacement from the transmitter coil.

2. An induction logging instrument according to claim 1 further comprising a cancellation coil supported on the former and connected with the receiver coils whereby current directly induced in a receiver coil may be cancelled.

3. An induction logging instrument according to claim 1 or 2 in which a plurality of transmitter coils are provided, each wound on magnetically permeable core material and supported at angularly spaced positions around the former.

4. An induction logging instrument according to claim 3 wherein the arrangement of transmitter coils is geometrically similar to the arrangement of receiver coils.

5. An induction logging instrument according to claim 3 or 4 including means for selectively activating each transmitter coil.

6. An induction logging instrument according to claim 5 in which the transmitter coils are selectively activated in a predetermined sequence.

7. An induction logging instrument according to any preceding claim in which the or each transmitter coil is activated with a pulsed current signal.

8. An induction logging instrument according to claim 3, 4, 5 or 6 wherein the cancellation coil comprises a plurality of coils arranged in a geometrically similar arrangement to the receiver coils.

9. An induction logging instrument according to any preceding claim in which the former is shielded from the transmitter coil by magnetically permeable core material which spaces the transmitter and receiver coils from the former.

10. An induction logging instrument according to claim 1 or 9 in which the transmitter coil comprises a single coil wound around the former.

11. An induction logging instrument according to claim 10 in which the cancellation coil comprises a single coil wound around the former.

12. A method according to any preceding claim in which the former comprises non-magnetic and non-conductive material.

13 . A method for measuring formation resistivity/ conductivity in each of a plurality of radial directions around a borehole comprising the steps of inserting an induction logging instrument into the borehole, activating at least one transmitter coil wound on magnetically permeable core material and supported on a former of the instrument and detecting current induced in at least one of a plurality of receiver coils each wound on magnetically permeable core material and supported at angularly spaced positions around the former at a predetermined axial displacement from the transmitter coil.

14. A method for measuring formation resistivity/ conductivity in each of a plurality of radial directions around a borehole according to claim 13 wherein the transmitter coil is activated with a pulsed signal.

15. A method for measuring formation resistivity/ conductivity in each of a plurality of radial directions around a borehole according to claim 13 or 14, wherein a plurality of transmitter coils are provided each wound on a core of magnetically permeable core material and supported at angularly spaced positions around the former and the coils are selectively activated.

16. A method according to claim 15 wherein the transmitter coils are selectively activated in a predetermined sequence.

17. A method according to claims 13, 14, 15 or 16 in which the or each transmitter coil is spaced from the former by a core of magnetically permeable core material.

18. A method according to claims 13, 14, 15, 16 or 17 in which the former comprises non-magnetic non-conductive material.

19. An induction logging instrument substantially as herein described with reference to any of figures 5 and 6, 7, 8, 9, 10, 11 or 12 of the drawings.

19. A method for measuring formation resistivity/ conductivity substantially as herein described.

The Patent Office

Application No:	GB 9504482.2	**Examiner:**	Mr A Oldershaw
Claims searched:	1 to 20	**Date of search:**	22 May 1995

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.N): G1N NCLF

Int Cl (Ed.6): G01V

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP0475715A2	(BAKER-HUGHES) - see figs 5,6,10-11B; col.3 ll.7-9; col.5 ll.39-43; col.7 ll.11-29; col.8 ll.15-23	1,13 at least
X	US5095272	(HALLIBURTON)	1,13 at least
X	US4302723	(SCHLUMBERGER)	1,13 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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